MODEL-BASED CONTROL FOR TORQUE BIASING SYSTEM

FIELD OF THE INVENTION

[0001] The present invention relates to torque biasing systems, and more particularly to model-based control of a torque biasing system.

BACKGROUND OF THE INVENTION

[0002] Torque biasing systems can be implemented in vehicle components including, but not limited to, a transfer case, a power take-off unit (PTU) and an axle. Torque biasing systems regulate torque transfer between an input and an output. More specifically, a clutch pack is operably disposed between the input and the output. The degree of engagement of the clutch pack is varied to regulate the amount of torque transferred from the input to the output. For example, when the clutch pack is disengaged, there is no torque transfer from the input to the output. When the clutch pack is fully engaged or locked, all of the torque is transferred from the input to the output. When partially engaged, a corresponding portion of the torque is transferred from the input to the output.

[0003] The degree of clutch pack engagement is adjusted by a linear force that is imparted on the clutch pack via an actuator system. Traditional actuator systems include an electric motor and a clutch operator mechanism. The clutch operator mechanism converts the torque generated by the electric motor into the linear force, which can be amplified prior to being imparted on the

clutch pack. The electric motor is controlled based on a control signal generated by a control system.

[0004] Conventional control systems use closed-loop control to regulate a specified system parameter. When the specified system parameter has an accurate means of feedback, such as is the case with direct sensing, the overall system accuracy is sufficient. In the case where the specified system parameter is not directly measurable, system accuracy is difficult to achieve.

[0005] Torque biasing systems are typically controlled based on a parameter other than torque, because torque is not easily measurable and torque sensors are not readily available. Torque sensors, however, would not be a total solution because the actual torque generated by a vehicle system is often much slower than is required by the biasing device. As a result, conventional torque biasing systems are not controlled as accurately as is desired.

SUMMARY OF THE INVENTION

[0006] Accordingly, the present invention provides a method of controlling a torque biasing system. The method includes determining a torque command, calculating a torque error based on the torque command and a model-based torque. A control signal is generated based on the torque error and the torque biasing system is operated based on the control signal.

[0007] In one feature, the method further includes processing a previous control signal through a torque biasing system model to generate the model-based torque. The torque biasing system model includes a motor model,

a clutch operator model and a clutch model. The control signal is processed through the motor model to generate a clutch operator interconnection value. The clutch operator interconnection value is generated based on a resistance torque, a motor position signal and motor data.

[0008] In still another feature, the method further includes calculating the resistance torque using the clutch operator model. An interconnection position value is processed through the clutch operator model to generate a clutch interconnection value. The clutch interconnection value is generated based on a resistance force and clutch operator data. The resistance force is calculated using the clutch model.

[0009] In yet another feature, the method further includes processing a clutch interconnection value through the clutch model to generate the model-based torque.

[0010] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0012] Figure 1 is a schematic illustration of a vehicle including a transfer case that incorporates an exemplary torque biasing system;

[0013] Figure 2 is a logic diagram illustrating a model-based control system according to the present invention;

[0014] Figure 3 is a logic diagram illustrating a torque biasing system model according to the present invention;

[0015] Figure 4 is a logic diagram illustrating a motor module according to the present invention;

[0016] Figure 5 is a logic diagram illustrating a clutch operator module according to the present invention; and

[0017] Figure 6 is a logic diagram illustrating a clutch module according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] The following description of the preferred embodiments is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. As used herein, the term module refers to an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that execute one or more software or firmware programs, a combinational logic circuit, or other suitable components that provide the described functionality.

[0019] Referring now to Figure 1, a four-wheel drive vehicle 10 is illustrated. The vehicle includes a front drive line 22, a rear drive line 24, and a

power source, such as an engine 26 (partially shown), which provides drive torque to the front and rear drive lines through a transmission 28. The transmission 28 may be either a manual or automatic shifting type. The front drive line 22 includes a pair of front wheels 30 connected to opposite ends of a front axle assembly 32 having a front differential 34. The front differential 34 is coupled to one end of a front prop shaft 36, the opposite end of which is coupled to a front output shaft 38 of a transfer case 40. Similarly, the rear drive line 24 includes a pair of rear wheels 42 connected to opposite ends of a rear axle assembly 44 having a rear differential 46. The rear differential 46 is coupled to one end of a rear prop shaft 48, the opposite end of which is coupled to a rear output shaft 50 of the transfer case 40. The transfer case 40 is equipped with an electronically-controlled torque biasing system 52 that is operable to control the magnitude of speed differentiation and torque distribution between the output shafts 38 and 50.

[0020] Adaptive actuation of the torque biasing system 52 is controlled by a control system that includes a group of sensors 56 for monitoring specific dynamic and operational characteristics of the vehicle 10 and generating sensor signals indicative thereof, and a controller 58 for generating control signals in response to the sensor input signals. Moreover, the controller 58 is adapted to control the actuated condition of torque biasing system 52 by generating digital control signals based on both the sensor input signals and torque biasing system model of the present invention.

[0021] A mode select mechanism 60 enables a vehicle operator to select one of the available drive modes. In particular, the controller 58 controls the torque biasing system 52 in response to a mode signal sent to the controller 58 from mode select mechanism 60. The mode signal indicates the particular drive mode selected. When an "adaptive" four-wheel drive mode is selected, the controller 58 operates to continuously monitor and automatically regulate the actuated condition of torque biasing system 52 between its non-actuated and fully actuated limits, thereby varying the magnitude of speed differentiation and torque distribution between output shafts 38 and 50. When the mode signal indicates that a "locked" four-wheel drive mode has been selected, the torque biasing system 52 is fully actuated, whereby non-differentiated power is delivered to output shafts 38 and 50. The locked four-wheel drive mode is provided to permit improved traction when the vehicle is operated off road or over severe road conditions.

[0022] Referring now to Figure 2, a schematic illustration of the torque biasing system 52 is shown. The torque biasing system 52 includes a motor 70, a clutch operator mechanism 72 and a clutch-pack 74. It is anticipated that the clutch operator mechanism includes a driven torque/force conversion device with an amplifier mechanism. Anticipated drivers include motors or solenoids. Anticipated torque/force conversion devices include cam/follower devices, dual cam plate devices and scissor plates and anticipated amplifier mechanisms include levers and ball ramps. An input torque (T_{INPUT}) is transferred through the clutch-pack 74 to provide an output torque (T_{OUTPUT}). The motor 70 is operated

based on a control signal to manipulate the clutch operator mechanism 72. The gear reduction/shift lever system 72 imparts a linear force on the clutch-pack 74 that regulates engagement of the clutch-pack 74. T_{OUTPUT} is based on the degree of clutch-engagement. The controller 58 generates the control signal as discussed in detail below.

[0023] Referring now to Figure 2, the model-based control of the present invention will be described in detail. A torque command (T_{COM}) is generated based on vehicle inputs. T_{COM} is the amount of torque that is to be transferred through the torque biasing system 52 and is a running calculation based on wheel speeds, yaw rate, throttle and the like. The wheel speeds, yaw rate and throttle signals are generated by the sensor group 56. A summer 78 generates a torque error (T_{ERROR}) as the difference between T_{COM} and a model-based torque (T_{CALC}). The model-based control is implemented via a motor module 80, a clutch operator module 82 and a clutch module 84 as described in further detail below. More particularly, the motor module 80 is based on a motor model, the clutch operator module 82 is based on a shift system model and the clutch module 84 is based on a clutch model.

[0024] A motor control module 86 generates a motor voltage (V_{MOTOR}) based on T_{ERROR} and a motor position signal (M_{POS}). The motor control module 86 is preferably a proportional, integral, derivative (PID) control module of a type known in the art. The motor 70 operates based on V_{MOTOR} and includes a position sensor 88 and a temperature sensor 90. The position sensor 88 generates M_{POS}, which indicates the rotational position of the motor armature (not

shown). The temperature sensor 90 generates a motor temperature signal (M_{TEMP}). The motor 70 generates a torque (T_{MOTOR}) that drives the shift system 72.

[0025] The shift system 72 generates a linear force (F) that is imparted on the clutch pack 74. F controls the engagement of the clutch pack 74. More particularly, as F increases, clutch slip is decreased until lock-up is achieved. During clutch slip, the input torque (T_{INPUT}) is greater than the output torque (T_{OUTPUT}). At clutch lock-up, T_{INPUT} is equal to T_{OUTPUT}. In other words, all of T_{INPUT} is transferred through the clutch-pack 74 during clutch lock-up. The clutch-pack 74 includes a temperature sensor 92 that generates a temperature signal (C_{TEMP}).

[0026] Referring now to Figure 3, T_{CALC} is determined based on motor data, V_{MOTOR}, M_{POS}, M_{TEMP}, I_{MOTOR}, shift system data and clutch data. More particularly, the motor module 80 determines a physical characteristic of the motor 70 (i.e., armature position) based on electrical motor characteristics (i.e. the motor data, V_{MOTOR} and I_{MOTOR}) and physical motor characteristics (i.e., M_{POS} and M_{TEMP}). The motor module 80 also accounts for the gear ratios of the gear reduction system. The motor module 80 generates a clutch operator interconnection position (P_{COINT}) based on the motor data, V_{MOTOR}, M_{POS} and M_{TEMP} and a resistance torque (T_{RES}). T_{RES} is determined as discussed in further detail below. P_{COINT} indicates the rotational position of the physical component (e.g., screw) that interconnects the motor 70 and the clutch operator mechanism 72.

[0027] The clutch operator module 82 determines a clutch interconnection position (P_{CINT}) based on the clutch operator data, P_{COINT} and a resistance force (F_{RES}). F_{RES} is determined by the clutch model 84 as discussed in further detail below. The shift system module 82 also calculates T_{RES}, which is fed back to the motor module 80. The clutch module 84 calculates T_{CALC} based on clutch data, C_{TEMP}, wheel velocities, a nominal kiss point (NOM_{KP}) a corrected kiss point ($CORR_{KP}$) and P_{CINT}. The clutch module 84 also calculates F_{RES}, which is fed back to the shift system module 82.

[0028] Referring now to Figure 4, the motor module 80 will be discussed in further detail. The motor data is provided by the motor manufacturer and includes a current to torque conversion factor (k_T) a back EMF constant (k_E), brake on drag, brake off drag, viscous drag, coil resistance (R_{COIL}), inertia and gear ratio. The motor module 80 includes a current calculating module 100, a drag torque calculating module 102, a velocity calculating module 104 and a position calculating module 106. The current calculating module 100 calculates a current (I) based on V_{MOTOR}, R_{COIL}, k_E, I_{MOTOR} and an angular velocity (ω_{MOTOR}). ω_{MOTOR} is calculated by the velocity calculating module 104 as discussed in further detail below. A multiplier 108 multiplies I by k_T to provide an indicated motor torque ($T_{MOTORIND}$).

[0029] The drag torque calculating module 102 calculates a brake drag torque ($T_{DRAGBRK}$) and a viscous damper drag torque (T_{DRAGVD}) based on ω_{MOTOR}, a brake enable signal and the viscous drag motor data. More particularly, $T_{DRAGBRK}$ is calculated based on ω_{MOTOR} and either the brake on drag or the

brake off drag motor data. If the brake enable signal indicates brake on, $T_{DRAGBRK}$ is determined based on the brake on drag motor data. If the brake enable signal indicates brake off, $T_{DRAGBRK}$ is determined based on the brake off motor data. T_{DRAGVD} is determined based on ω_{MOTOR} and the viscous drag motor data. $T_{DRAGBRK}$ and T_{DRAGVD} are subtracted from T_{MOTOR} by a summer 110 to provide an adjusted motor torque ($T_{MOTORADJ}$).

[0030] T_{RES} is subtracted from $T_{MOTORADJ}$ by a summer 112 to provide an acceleration motor torque ($T_{MOTORACC}$). $T_{MOTORACC}$ is multiplied by the inertia motor data to provide an angular acceleration (α_{MOTOR}). The velocity calculating module 104 calculates ω_{MOTOR} based on α_{MOTOR} and a time step (t_K). The position calculating module 106 calculates P_{COINT} based on ω_{MOTOR}, M_{POS}, t_K and the gear ratio motor data.

[0031] Referring now to Figure 5, the clutch operator module 82 will be explained in detail. The clutch operator data includes a spring rate (k_{SPRING}), an efficiency (CO_{EFF}), a drag factor (CO_{DRAG}), a viscous damper drag factor (CO_{DRAGVD}), a position ratio (CO_{RATIO}) and an inertia ($CO_{INERTIA}$). The clutch operator module 82 includes a drag calculating module 114, a velocity calculating module 116 and a position calculating module 118. A clutch operator position (P_{CO}) is subtracted from P_{COINT} by a summer 120 to provide a position error (P_{ERROR}). P_{CO} is calculated by the position calculating module 118 as discussed below. A multiplier 122 multiplies P_{ERROR} and k_{SPRING} to provide T_{RES}.

[0032] The drag calculating module 114 calculates a clutch operator torque (T_{CO}) based on CO_{EFF}, CO_{DRAG}, CO_{DRAGVD}, T_{RES} and a clutch operator

angular velocity (ω_{CO}). More particularly, the drag calculating module 114 updates T_{RES} to account for efficiency losses and calculates a drag torque and a viscous damper drag torque. The drag torque and viscous damper drag torque are subtracted from the updated T_{RES} to provide T_{CO}. An inertia torque ($T_{INERTIA}$) is determined as the product of F_{RES} and CO_{RATIO} by a multiplier 124. $T_{INERTIA}$ is subtracted from T_{CO} by a summer 126 to provide a clutch operator acceleration torque (T_{COACC}). A clutch operator angular acceleration (α_{CO}) is determined as the product of T_{COACC} and $CO_{INERTIA}$ by a multiplier 128. The velocity calculating module 116 calculates ω_{CO} based on α_{CO} and t_K. The position calculating module 118 calculates P_{CO} based on ω_{CO} and t_K. P_{CINT} is determined as the product of P_{CO} and CO_{RATIO} by a multiplier 130.

[0033] Referring now to Figure 6, the clutch module 84 will be described in detail. The clutch data includes an active ready control factor and a back stop position. The clutch module 84 includes a force calculating module 132, a slip speed calculating module 134, a friction module 136 and a torque calculating module 138. The force calculating module 132 determines F_{RES} and a clutch force (F_{CLUTCH}) based on the clutch data, a nominal kiss point (KP_{NOM}), P_{CINT} and a kiss point correction (KP_{CORR}). More particularly, P_{CINT} is corrected based on KP_{CORR}. KP_{CORR} is continuously updated to account for tolerances and wear in the clutch. F_{CLUTCH} is determined from a series of look-up tables based on the corrected P_{CINT}. F_{CLUTCH} is determined from test data averaged from various torque biasing systems instrumented to measure force at the clutch based on actuator position. Because there is normally a difference between

engaging and releasing (i.e., hysteresis) multiple traces are collected. The direction of travel determines which table is used and filtering is applied to ensure smooth transitions.

[0034] F_{CLUTCH} is further determined based on a negative clutch force ($F_{CLUTCHNEG}$), the corrected P_{CINT}, KP_{NOM} and the active ready control factor. $F_{CLUTCHNEG}$ is a fictitious number that implies that the "actual" torque at the clutch is negative when the system is below the kisspoint of the clutch. In this manner, the system is maintained at the active ready position when there is a low torque request. This is achieved by providing a significant control error if the position is below the kisspoint. Without $F_{CLUTCHNEG}$, the system would calculate zero torque for any position below the kisspoint causing minimal control error for low torque requests regardless of position. Additionally, $F_{CLUTCHNEG}$ is a direct gain on position below kisspoint and is tuned for optimum response and stability. KP_{NOM} is a constant that is stored in memory and indicates the nominal kiss point (i.e., the point at which the clutch plates engage) for the particular clutch model. F_{CLUTCH} is calculated as the difference of $F_{CLUTCHINT}$ and $F_{CLUTCHNEG}$.

[0035] The slip speed calculating module 134 calculates wheel slip (v_{SLIP}) based on the wheel speed signals generated by the sensor group 56. The friction calculating module 138 calculates a coefficient of friction (K_{FRICT}) based on F_{CLUTCH}, v_{SLIP} and C_{TEMP}. More particularly, the friction module 136 determines K_{FRICT} from a three-dimensional look-up table based on F_{CLUTCH}, v_{SLIP} and C_{TEMP}. The torque calculating module 138 calculates T_{CALC} based on K_{FRCIT} and F_{CLUTCH}. T_{CALC} is determined according to the following equation:

$$T_{CALC} = F_{CLUTCH} * N_{PLATES} * R_{EFF} * K_{FRICT}$$

where N_{PLATES} is the number of clutch plates and R_{EFF} is the effective radius of the clutch plates. N_{PLATES} and R_{EFF} are constants based on clutch geometry. No hysteresis is assumed.

[0036] The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.